PAPER • OPEN ACCESS

Rheological Properties and Microstructure of AlSi10Mg Aluminum Alloy produced by Selective Laser Melting

To cite this article: D R Salikhyanov *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **709** 033113

IOP Conf. Series: Materials Science and Engineering **709** (2020) 033113 doi:10.1088/1757-899X/709/3/033113

Rheological Properties and Microstructure of AlSi10Mg Aluminum Alloy produced by Selective Laser Melting

D R Salikhyanov[1,2*], S V Gladkovskii[2,1], Yu A Avraamov[3], V P Volkov[2] and V E Veselova[2]

[1] Institute of New Materials and Technologies, Ural Federal University named after the first President of Russia B.N. Yeltsin, Ekaterinburg, 620002, Russian Federation
[2] Institute of Engineering Science, Ural Branch of the Russian Academy of Sciences, Ekaterinburg, 620049, Russian Federation
[3] Regional Engineering Centre of Additive Technologies, Ural Federal University named after the first President of Russia B.N. Yeltsin, Ekaterinburg, 620078, Russian Federation

* d.r.salikhianov@urfu.ru

Abstract. The present study is focused on rheological properties of AlSi10Mg aluminium alloy produced by selective laser melting (SLM) at temperatures of hot deformation with the aim to investigate the dependence of strain resistance on temperature, strain rate and strain degree. As-build cylindrical specimens made of AlSi10Mg aluminium alloy was examined on a cam plastometer in temperature range 20 – 500 °C, at strain rate ξ equal to 1, 10 s^{-1} up to strain degree e equal to 1.2. The paper presents results of study of initial microstructure, microhardness measurement and flow curves of AlSi10Mg alloy produced by SLM. The flow curves of AlSi10Mg alloy produced by SLM can be used in the computer simulation and development of new manufacturing methods of the metallic parts by additive technologies with the use of deformation post-treatment.

1. Introduction

Nowadays, additive manufacturing (AM), the layer-by layer building-up of parts from metals and alloys, represents an option for small scale production due to advantages such as reduction in lead-time, reduced material wastage, freedom in the design of the parts [1–9]. The parts made of aluminium alloys, especially from AlSi10Mg, find their application in aerospace, automotive industries and heat exchanger products, due to its light weight, high mechanical properties, low thermal expansion and recycling costs [10–12]. In [13], K. Kempen et al. report that parts made from SLM AlSi10Mg alloy have mechanical properties – hardness, ultimate tensile strength, ductility, impact energy higher or at least comparable to the casted AlSi10Mg material. However, the use of SLM AlSi10Mg aluminium alloy is still quite limited due to a problem of enhanced porosity [11, 12, 14]. In addition, the disadvantages related to SLM are anisotropy of mechanical properties, high residual stresses, inhomogeneous microstructure of parts [15].

In order to reduce porosity of SLM-ed parts, the following methods have been developed and investigated: optimization of sintering parameters (“scanning strategy”): hatch spacing, scanning speed, scan orientation [11, 12]; heat treatment [10, 14, 16], platform heating [14]. Also, it is worth to mention the methods based on deformation post-treatment which allows to significantly improve the mechanical properties of AM-ed parts: hot isostatic pressing (HIP) [17, 18], technology of AM combined with the rolling of each built-up layer by a roller [19 – 21]. From the abovementioned works follows that introduction the deformation treatment into AM has a positive effect on the properties of metal parts – internal pores and microcracks are welded, properties anisotropy is eliminated, strength, plastic and fatigue properties become higher. Thus, AM with the use of deformation post-treatment can be a promising direction.

The rheological properties of metals in a wide range of temperatures are of interest for research, because they allow to find the optimal technological parameters for the processes of pressure treatment of AM-manufactured parts. However, literary review has shown that for AlSi10Mg aluminium alloy produced by SLM-technology, such data absent. The limited literature presents only tensile curves of SLM AlSi10Mg alloy at room temperature [10, 13, 16]. Thus, the aim of this research work is to determine the rheological properties of AlSi10Mg aluminium alloy produced by SLM at hot deformation temperatures. The resulting flow curves of the materials can be used in the computer simulation processes of new manufacturing methods of additive technologies with the use of deformation post-treatment.

2. Materials and research methods

Strain resistance of AlSi10Mg aluminium alloy specimens fabricated by SLM-method was studied using a cam plastometer with a working force up to 1500 kN placed at the collective use center «Plastometriya» of the Institute of Engineering Science of Ural Branch of the Russian Academy of Sciences by compression of cylindrical specimens according to the procedure described in [22 – 23]. Specimens from AlSi10Mg alloy was produced on the EOSINT M 280 additive machine at the Regional Engineering Centre of Additive Technologies of Ural Federal University. For producing aluminium alloy specimens, the following parameters were applied: laser beam power of 200 W, a scan speed of 500 mm/s, powder with spherical morphology and particle size 20 – 35 μm. Chemical composition of AlSi10Mg aluminium alloy (EOS's data) is given in Table 1. Cylindrical specimens from AlSi10Mg alloy 10 mm in diameter and 14 mm in height were used.

Table 1. Chemical composition of EOS's AlSi10Mg aluminium alloy, %.

Al	Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Sn	Ti
Bal.	9.0 – 11.0	≤0.55	≤0.05	≤0.45	0.2 – 0.45	≤0.05	≤0.10	≤0.05	≤0.05	≤0.15

Compression tests of the specimens were carried out in temperature range t = 20 – 500 °C with heating from room temperature, at strain rate ξ = 1.0, 10 s^{-1}. Strain rate during the whole process of compression was held constant due to the corresponding cam profile and automated regulated electric drive.

Before loading into the furnace for heating, specimens were set into a special cylindrical container (Fig. 1) on a centre of deforming anvils made of special heat-resistant alloy and insulated with kaolin wadding. To provide the uniform deformation and uniaxial compressive stress state a lubricant in the form of ground glass containing 55 % SiO_2, 7 % BO_2, 21 % Al_2O_3, 14 % CaO was used. Heating specimens to test temperatures was performed in an electric furnace with the container.

After attaining the specified temperature, the container with the specimen was extracted from the furnace and set into a working place of the plastometer on the load cell along its axis, then the specimen was immediately compressed with an automatic registration of current height and force on a computer. Registered compression parameters were processed using a program by formula $\sigma_s = P/F$, where P is the measured force, F is the calculated cross section area. As a result, the flow curves of the materials under investigation were defined.

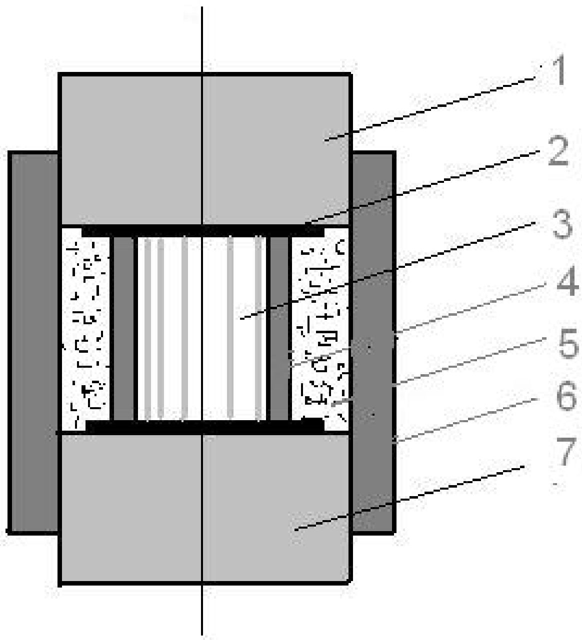

Figure 1. Assembly scheme of a container with a specimen for compression: 1 – upper deforming anvil; 2 – lubricant layer; 3 – specimen; 4 – asbestos insulation; 5 – kaolin wadding; 6 – steel container; 7 – lower deforming anvil.

Additionally, metallographic studies of specimens made of AlSi10Mg alloy after etching in the reagent (5 ml. HF + 95 ml. H_2O) were performed. Microhardness was measured on microhardness tester with an integrated optical microscope Shumadzu HMV-G21DT.

3. Results and discussion

Results of the study of microstructure of AlSi10Mg aluminium alloy on an optical microscope are presented in Fig. 2. On the surface of the microsection (Fig. 2, a) it is can be seen a large number of pores, both individual and lined up, with a pore diameter of 25 μm. According to the phase diagram [14], the structure of the specimens after etching (Fig. 2, b, c) consists of large dendritic grains of α-Al and Si formed from the eutectic during rapid cooling. Vickers microhardness HV0,025 is 133 for AlSi10Mg alloy.

Results of plastometric tests – the flow curves of AlSi10Mg aluminium alloy in the form of a dependence of strain resistance σ_s on true strain e ($e = \ln(h_0/h_i)$, where h_0 and h_i are initial and current specimen height, respectively) are presented in Fig. 3 at various test temperatures. Features of resulting flow curves are the following: 1) the specimens have fractured at test temperature of 20 °C and at strain rate ξ of 1, 10 s^{-1}; 2) An intensive hardening following by subsequent softening (peak stress) can be observed at test temperature of 300 °C and at strain rate ξ of 1, 10 s^{-1}; 3) strain resistance goes to the level of steady state stress without observable peak stresses at test temperature of 400 and 500 °C; 4) with increasing strain rate ξ, strain resistance σ_s increases. This pattern coincides with the data for casted Al alloys described in [24].

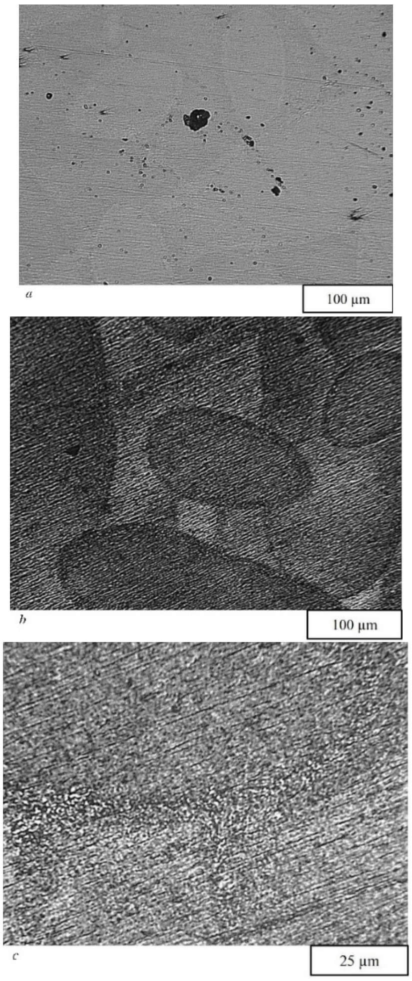

Figure 2. Microstructure of AlSi10Mg aluminium alloy produced by SLM: a – polished, unetched, x100; b – etched, x100; c – etched, x400.

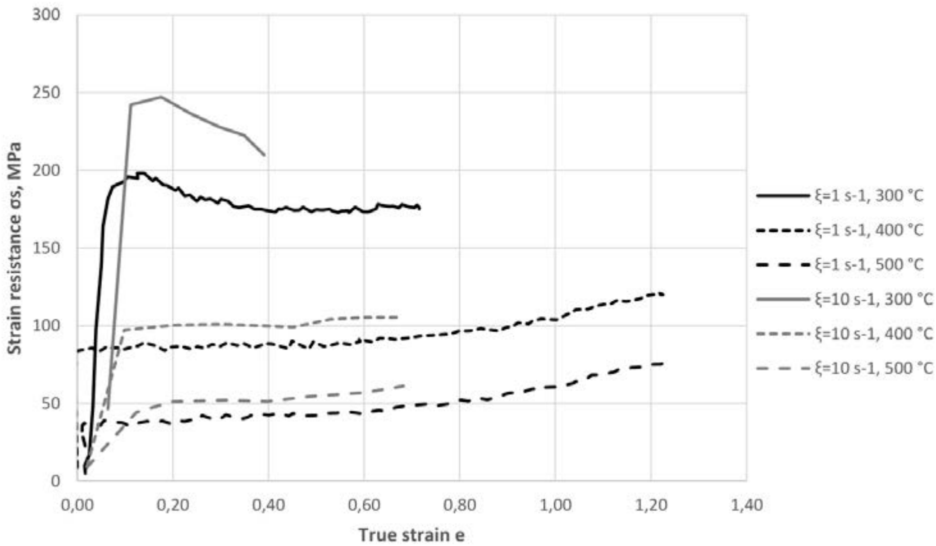

Figure 3. The flow curves of AlSi10Mg aluminium alloy at temperatures of hot deformation.

IOP Conf. Series: Materials Science and Engineering **709** (2020) 033113 doi:10.1088/1757-899X/709/3/033113

4. Summary

In the present research work, the study of rheological properties of AlSi10Mg aluminium alloy produced by SLM was carried out at temperatures of 20 – 500 °C, at strain rate ξ of 1, 10 s^{-1} up to strain degree *e* equal to 0.7 – 1.2.

Acknowledgement

The study was made within the basic part of the state job in the field of scientific activity No. 11.9538.2017/8.9 and was supported by Act 211 of the Government of the Russian Federation (agreement No. 02.A03.21.0006).

References

[1] Herzog D, Seyda V, Wycisk E, Emmelmann C, 2016, Additive manufacturing of metals, Acta Materialia, 117, 371 – 392.
[2] Murr LE, Gaytan SM, Ramirez DA et al., 2012, Metal Fabrication by Additive Manufacturing Using Laser and Electron Beam Melting Technologies, J. Mater. Sci. Technol., 28(1), 1 – 14.
[3] DebRoy T, Wei HL, Zuback JS et al., 2018, Additive manufacturing of metallic components – Process, structure and properties, Progress in Materials Science, 92, 112 – 224.
[4] Sames WJ, List FA, Pannala S, Dehoff RR and Babu SS, 2016, The metallurgy and processing science of metal additive manufacturing, International Materials Reviews, 61(5), 315 – 360.
[5] Korner C, 2016, Additive manufacturing of metallic components by selective electron beam melting — a review, International Materials Reviews, 61(5), 361 – 377.
[6] Bourell DL, 2016, Perspectives on Additive Manufacturing, Annual Review of Materials Research, 46(1), 1 – 18.
[7] King WE, Anderson AT, Ferencz RM et al., 2015, Laser powder bed fusion additive manufacturing of metals; physics, computational, and materials challenges, Applied Physics Reviews, 2(4), 1 – 26.
[8] Gu DD, Meiners W, Wissenbach K and Poprawe R, 2012, Laser additive manufacturing of metallic components: materials, processes and mechanisms, International Materials Reviews, 57(3), 133 – 164.
[9] Niaki MK, Nonino F, 2017, Additive manufacturing management: a review and future research agenda, International Journal of Production Research, 55(5), 1419 – 1439.
[10] Li W, Li S, Liu J et al., 2016, Effect of heat treatment on AlSi10Mg alloy fabricated by selective laser melting: Microstructure evolution, mechanical properties and fracture mechanism, Materials Science & Engineering A, 663, 116 – 125.
[11] Read N, Wang W, Essa K, Attallah MM, 2015, Selective laser melting of AlSi10Mg alloy: Process optimisation and mechanical properties development, Materials and Design, 65, 417 – 424.
[12] Aboulkhair NT, Everitt NM, Ashcroft I, Tuck C, 2014, Reducing porosity in AlSi10Mg parts processed by selective laser melting, Additive Manufacturing, 1–4, 77 – 86.
[13] Kempen K, Thijs L, Van Humbeeck J, Kruth J-P, 2012, Mechanical Properties of AlSi10Mg Produced by Selective Laser Melting, Physics Procedia, 39, 439 – 446.
[14] Brandl E, Heckenberger U, Holzinger V, Buchbinder D, 2012, Additive Manufactured AlSi10Mg Samples Using Selective Laser Melting (SLM): Microstructure, High Cycle Fatigue, and Fracture Behavior, Materials and Design, 34, 159 – 169.
[15] Sarkar S, Kumar CS, Nath AK, 2017, Effect of different heat treatments on mechanical properties of laser sintered additive manufactured parts, Proceedings of the ASME 2017 12th International Manufacturing Science and Engineering Conference, 1 – 7.
[16] Zyguła K, Nosek B, Pasiowiec H, Szysiak N, 2018, Mechanical properties and microstructure of AlSi10Mg alloy obtained by casting and SLM technique, World Scientific News, 104, 462 – 472.
[17] Kasperovich G, Hausmann J, 2015, Improvement of fatigue resistance and ductility of TiAl6V4

IOP Conf. Series: Materials Science and Engineering **709** (2020) 033113 doi:10.1088/1757-899X/709/3/033113

processed by selective laser melting, Journal of Materials Processing Technology, 220, 202 – 214.
[18] Atkinson HV, Davies S, 2000, Fundamental aspects of hot isostatic pressing: An overview, Metallurgical and Materials Transactions A, 31(12), 2981 – 3000.
[19] Colegrove PA, Martina F, Roy MJ et al., 2014, High pressure interpass rolling of Wire + Arc Additively Manufactured titanium components, Advanced Materials Research, 996, 694 – 700.
[20] Sames WJ, List FA, Pannala S et al., 2016, The metallurgy and processing science of metal additive manufacturing, International Materials Reviews, 61(5) 315 – 360.
[21] Friel RJ, Harris R, 2013, Ultrasonic Additive Manufacturing – A Hybrid Production Process for Novel Functional Products, Procedia CIRP, 6, 35 – 40.
[22] Loginov YuN, Gladkovskii SV, Potapov AI et al., 2015, Investigation into the deformation resistance of polycrystalline iridium, Russian Journal of Non-Ferrous Metals, 56(5), 532 – 539.
[23] Gladkovskii SV, Potapov AI, Salikhyanov DR, 2018, Rheological properties and substantiation of hot rolling regimes of low-and medium carbon structural steels, Solid State Phenomena, 284, 653 – 661
[24] Polukhin PI, Gun GYa, Galkin AM, 1983, Strain resistance of metals and alloys, Metallurgija, Moscow, *in Russian*.